An ESP using bipolar-discharge with DC high voltage for road tunnels

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1 Abstract:

Two-stage-type ESPs (electrostatic precipitators) are composed of ionizers and collectors. DC high voltage is applied to the discharge poles in the front stage ionizers. Particles passing through the space of positive or negative corona are charged. The rear stage collectors capture the particles. Although spike-typed dischargers are adopted widely, the spikes in this test are arranged not only in the voltage-applied plates but also in the earth-plates in the ionizer. As the test result, particles are collected by the discharge from both the voltage-applied plates and the earth-plates. The discharge in earth-plates generates ions with opposite polarity to that of voltage-applied plates. This bipolar collection method with the simultaneous positive-and-negative discharge shows a possibility that particles are efficiently captured not only on earth-plates but also on voltage-applied plates in the collector. This study implies the bipolar-discharge ESPs are suitable for smaller ESPs.

2 Introduction

The essence of the ESP specifications in Japan for purifying exhaust from car road tunnels is to be two-stage type with an ionizer and a collector and to pass the high wind velocity of 9 m/s [1]. A new type ESP with applying AC high voltage to a collector has recently emerged aiming at the same effect as making the area of collector plates larger [2].

The technology other than the above, as if collector area were made bigger, is shown only in a patent [3], whose spikes for corona discharge are arranged not only on high-voltage-applied plates but also on earth-plates in an ionizer. This means "bipolar charging" that positive and negative corona are generated simultaneously. In spite of its new idea, the patent includes no information of the collection efficiency, the dimensions around plates and the other numerical descriptions. It seems that there is no technology opened other than this patent which makes particle charging with bipolar discharger in an ionizer as the first stage of the ESP and captures them in a collector with DC high voltage as the second stage.

Thus the technology on bipolar discharge has been studied herein where positive and negative corona are simultaneously generated in an ionizer by using a high voltage power supply. The collection efficiency was compared. The purpose of this study is to realize smaller but high performance ESPs.

2.1 Methodology

Schematic of the bipolar corona discharge in an ionizer is shown in Fig. 2-1-1. The spikes on an edge of each metal plate are seen in (a). Positive or negative DC high voltage is applied to the plates whose spikes point to the windward. The plates whose spikes point to the leeward are earthed. Number of the plates of "spike windward" is less than that of the plates of "spike leeward" by one plate. When positive high voltage is applied to this configuration for example, positive corona is generated at the windward discharge space of F.D. (first discharge space) and negative corona at the leeward discharge space of S.D. (second discharge space). In case of applying negative high voltage, the spot of positive and negative corona are changed.

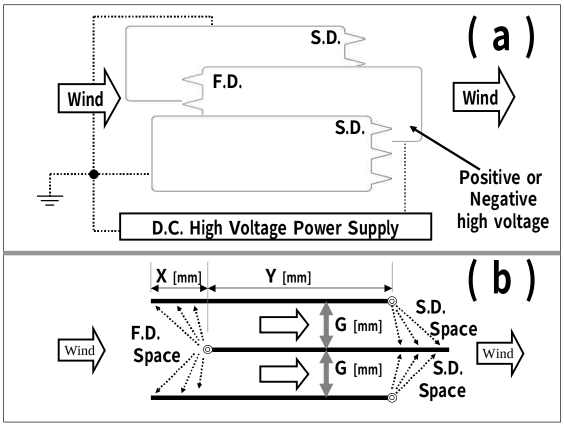

Fig. 2-1-1: Ionizer for bipolar corona discharge.

The lower part (b) in Fig. 2-2-1 is the bottom view of (a). The tip of each spike is marked as a dual-circle. The gap [mm] of adjoining plates is shown as "G". The distance [mm] between the tip of a spike and the nearest edge of the adjoining plate on the projected plane is called "X ". The distance between the tip of a spike and the tip of the spike on the adjoining plate is indicated as "Y ".

Each plate that is used this time has the same shape with the long side 100 mm, the short side 36 mm and thickness 0.4 mm. Three spikes are arranged on a short side of the plate with the pitch of 12 mm. Each spike has the shape of the tip angle 30 degrees and the height 10 mm from the short side to the tip. The plates are made of stainless steel 304.

The three cases of G are tested as 10, 15 and 20 mm. The six cases of X are selected for each G as 10, 20, 35, 50, 65 and 75 mm, although the only G10 case (G=10mm) has the further X05 case (X=5mm).

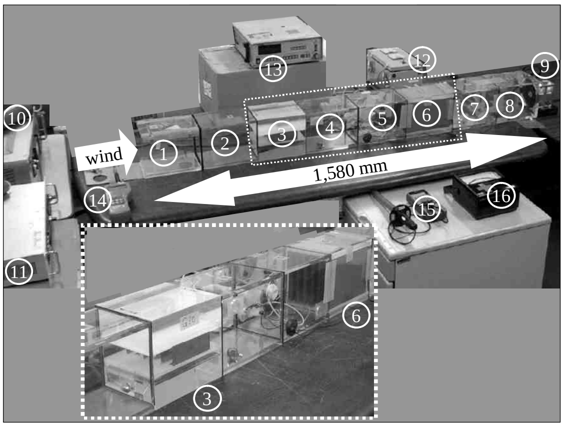

Fig. 2-3-2: Test equipment.

The test equipment is shown in Fig. 2-1-2. The ventilating duct system made of acrylic resin is composed of the parts from #1 to #9. The inlet part #1, the ionizer #3, the collector #6, and the outlet part is #9 with two axial flow fans coupled in series. The applied voltage to the ionizer is variable in both positive and negative case. The gap distance of 10 mm in the collector is fixed with the constant-applied voltage of -9 kV in order to grasp how the varied conditions at the ionizer affect the collection efficiency. The fans have a changeable frequency controller for keeping a constant flow rate against the various pressure drops at the ionizer. The hot-wire anemometer #14 is used for detecting the wind velocity at the inlet position. The inside of the ionizer duct is shrinked in order to obtain the high wind-velosity of 9 m/s. The positive high voltage power supply #10 and the negative supply #11 are switched for driving the ionizer.

Table 2-4-1: Test equipment.

Items	Details
Duct (#1,#2, #4,#5,#7,#8)	W 121, H 140, L 200 [mm] (Inside)
Ionizer (#3)	Duct ; W 121, H 32, L 180 [mm] (Inside) 5mm-pitch slits on ceiling and floor part. Type ; Parallel-flat-plates type Wind velocity rate ; 9 m/s In case of G10; 6 plates for F.D. & 7 for S.D. In case of G15; 4 plates for F.D. & 5 for S.D. In case of G20; 3 plates for F.D. & 4 for S.D.
Collector (#6)	Duct ; W 111, H 120, L 200 [mm] (Inside) Plate ; Thickness 0.4, H 124, L 200 [mm] 10mm-pitch slits on ceiling and floor part. Type ; Parallel-flat-plates type Wind velocity rate ; 2.6 m/s Amount of high-voltage-applied plates ; 6 Amount of earth-plates ; 6 Gap between adjacent two plates ;10mm
Fan (#9)	MU1238A-11B (Oriental Motor Co.,Ltd.) Quantity ; 2 (tandem coupled) With a variable frequency controller
High voltage power supply (#10)	Model-502 (Pulse Electric Engineering) Max. output ; DC+25kV , 25mA Stability 0.01%
High voltage power supply (#11)	MODEL-600F (Pulse Electric Engineering) Max. output ; DC-15kV , 30mA Stability 0.005%
High voltage power supply (#12)	APH-10K5N (Maxelec Co.,Ltd.) Adjusted output voltage ; DC-9kV (constant) Max current ; 30mA Ripple ; 0.02%
Particle counter (#13)	KC-01C (RION) , Light scattering method Range ; 0.3, 0.5, 1, 2, 5 over [micron meter] Sampling volume ; 0.01 CF (approx. 34 sec.)
Wind velocity Meter (#14)	Climomaster MODEL6531 (Kanomax) Mode;1 sec. measuring & 10 times ave.
Voltage meter & Probe (#15)	Digital multi meter type73303 (Yokogawa) Ratio;1/1000 (FLUKE), For high voltage
Current meter (#16)	Type 201133 (Yokogawa) Range; 0.1, 0.3, 1, 3 mA
Digital camera	DMC-FX01 Lumix (Panasonic) Mode; starry sky exposure; 60 sec.

The negative high voltage power supply #12 is for the collector. The voltage-applied plates and the earthed-plates have the same shape and the same number in the collector. A set of the probe and voltage meter of #15 is for measuring high voltage. The current meter is #16. In order to measure particle concentration, the particle counter #13 is used whose two sampling tubes for the windward of the ionizer and for the leeward of the collector are switched alternately. The collection efficiency is calculated by using all counts of all particle diameters not smaller than 0.3 micron meter. The particles to be removed in this study were those in the air in the laboratory room.

2.2 Results and discussion

The characteristics between the applied voltage and the discharge current in the ionizer are shown in Fig. 2-2-1. In cases of G10, G15 and G20, the characteristics of bipolar discharge with X10, X35 and X65 are indicated.

The condition of X05 is added only to G10. The dot-remarks of "positive" or "negative" in the figures mean if the voltage that is applied to the spikes pointing to the windward is positive or negative. The negative curves in G20 are cut off in the higher voltage range, because the maximum voltage of the negative power supply is only -15 kV. Each curve has three dots which are ranked in the order of power consumption of 1.3, 2.0 and 2.8 watts approximately.

In accordance with raising the voltage in each case, the discharge current increases relatively gradually. Each discharge current curve of the negative cases is larger than the one of the positive cases at the same voltage.

In cases of G15 and/or G20, the curves of "Positive X10" are extremely suppressed in the lower level. The case of G10 shows the same inclination in "Positive X05"

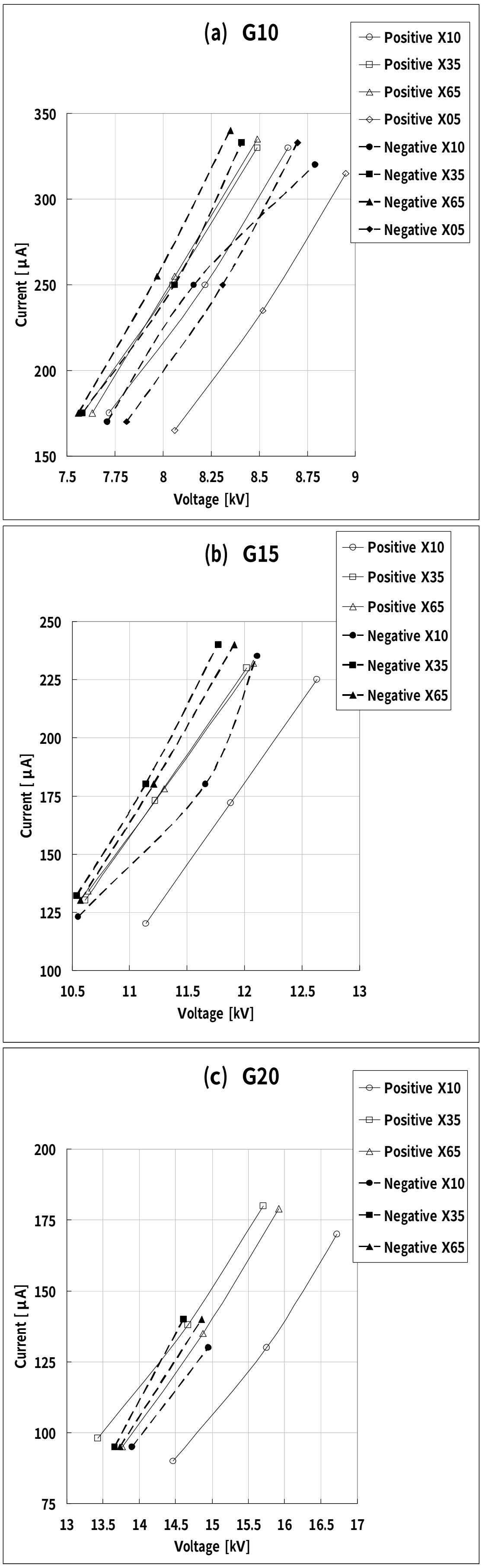

Fig. 2-2-1: V-I characteristics for each "G".

The characteristics of collection efficiency under the condition of keeping the passing wind velocity in the ionizer 9 m/s are shown in Fig.2-2-2.

For each G and each X, the applied voltage and the discharge current were increased i.e., with the increase of the power consumption, the collection efficiency was measured. As the parameters of the power consumption of 1.3 W, 2.0 W and 2.8 W, the collection efficiency was described for each G.

The range in which X is small is named "small X range". In case of G10, "small X range" lies in the area of less than 10 mm. In cases of G15 and G20, "small X range" is in the domain of less than 20 mm.

Except "small X range", **η** increases in accordance with raising the power in Fig. 2-2-2 and "Positive" shows the better **η** than "Negative". "Positive" means that the spikes pointing to the windward generate positive corona and the spikes pointing to the leeward do negative, which tells that "windward positive and leeward negative" shows the better **η** than "windward negative and leeward positive". This is a remarkable phenomenon in a series of these tests.

In case of G10, **η** gradually decreases with raising X. This reason is that the increased X means the decreased Y in Fig.2-1-1(b). The decreased Y is that the distance from positive spikes to negative spikes becomes shorter. In case of G15, the same inclination is seen although it is not so clear.

In case of G20, even if X is increased (i.e., Y is decreased), **η** almost keeps itself constant and stable without declination. That might be why the larger G ignores the decreased Y.

In "small X range", "Negative" shows the better **η** than "Positive". In other words "Positive" has extremely-worse characteristics in electrical charging in this range, although "Negative" has no big change. At minimum X, **η** of "Positive" at maximum power of 2.8 W shows the worst value. That is why negative corona as the opposite polarity is generated from the nearest edge of a plate adjoining to a "Positive" spike and as a result the capability of charging in the space might be deteriorated.

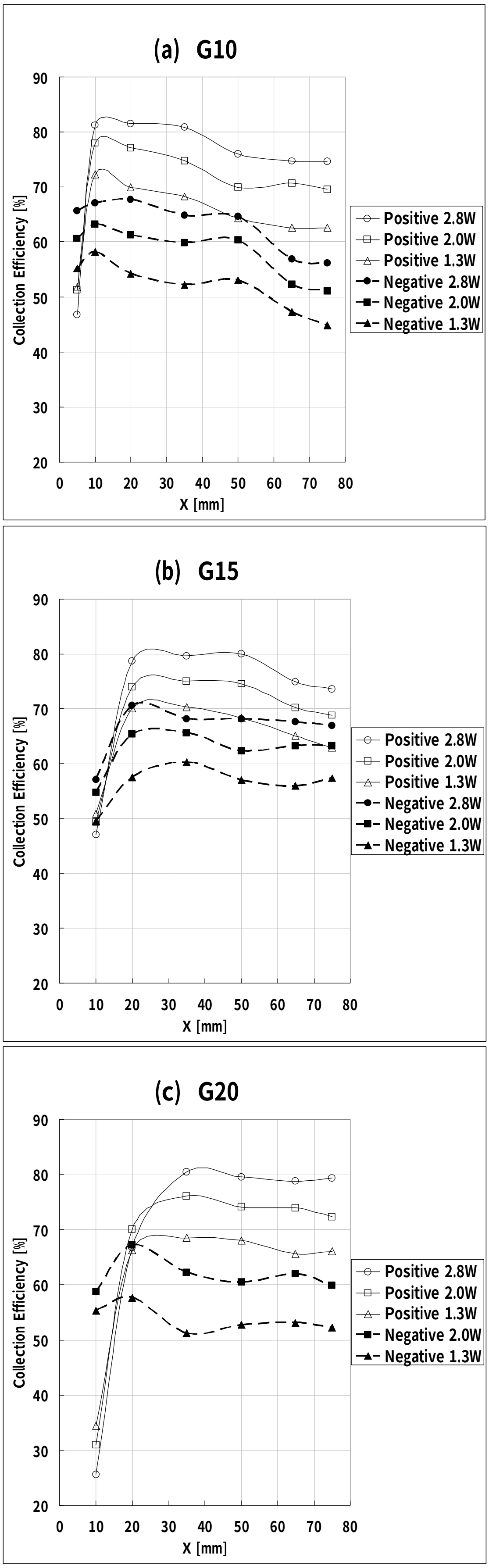

Fig. 2-2-2: "X" vs. **η** for each "G".

The aspects of bipolar discharge in the ionizer are shown with eight photos in Fig. 2-2-3. All pictures were taken in the dark with exposure time 60 seconds, although a torch was lit only on (a) during approximate one second. All photos were under the conditions of G20 X65. The wind velocity was 0 or 9 m/s. Positive voltage was applied to the spike on the left and the spikes on the right were earthed. The left side of photos is the windward.

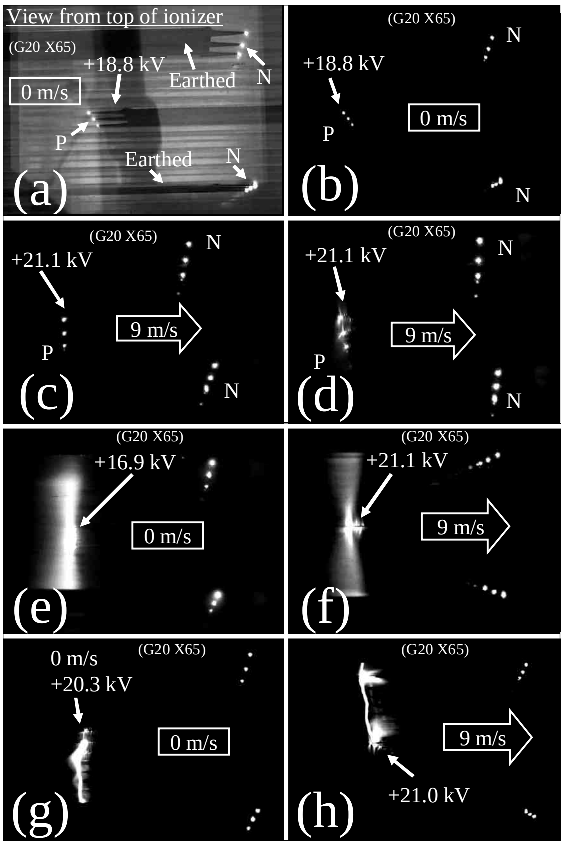

Fig. 2-2-3: Aspects of bipolar discharge.

Photo (a) was taken under the condition of "no wind". The shape of plates are vividly caught. Positive corona (glow) is seen from a tip of spike on the left. And negative corona is observed at the tips of spikes. The luminous strength of negative is slightly brighter than that of positive.

Photo (b) was taken under the same condition as (a) but in complete darkness.

Spark voltage Vs with wind 9m/s was higher than Vs without wind. Photo (c) was taken with wind. Positive glow was seen. Even if it was under the same condition, Pre-breakdown streamer like (d) was sometimes observed on the other chances. The streamer (d) grew most violently into (f) finally. The streamer (e) was pre-breakdown streamer without wind and emerged under the lower voltage than the one of windy (f). Whereas the width of the luminous belt by pre-breakdown streamer (e) was wide, the width of the streamer belt of (f) became narrower due to the high wind speed 9 m/s. This fact tells that not only gas molecules but also gas ions are flowing by ventilation. The reason of the larger Vs with wind is that the density of gas ions becomes lower because of flowing. And the capability of gas insulation is improved. [4]

The scenes of (g) and (h) show that sparks break out from the spike on the left. The luminous part of windy (h) by ionization and/or excitation at sparks flows away to the leeward whereas it seems not to flow away in the photo of (g) without wind.

A discussion point should be why "windward positive corona" leads to the better η comparing to "windward negative". In order to grasp the current ratio of positive discharge and negative discharge under the condition of bipolar discharge, the plates connected to earth line were divided into two parts. The first part was for positive discharge and the second part for negative discharge. With connecting two current meters to both parts of divided earth-plates with spikes, both positive and negative discharge current were measured in cases of G15 X35 and G15 X10. The ratio of positive discharge current to total discharge current is shown in Fig. 2-2-4. (These lines also express the ratio of power consumption of positive corona to both coronas.)

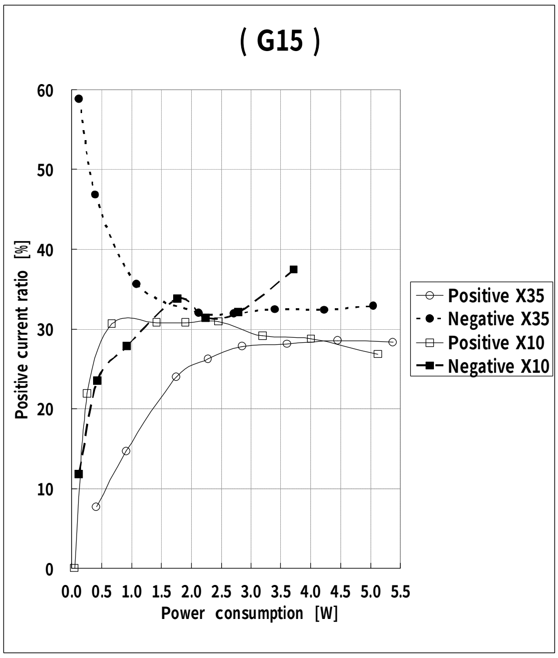

Fig. 2-2-4: Ratio of positive discharge.

The power consumption of this type of ESP is considered more than 1.5 kW. The ratio of positive discharge is from 20% to 40% in the range over 1.5 kW i.e., negative discharge is stronger than positive under the same voltage.

This result is fairly similar to some reports in case of “mono-polar discharge” that negative discharge gives the larger current than positive discharge [5][6].

In case of “windward positive”, particles are charged positive in the discharge space at the windward i.e., F.D. (first discharge space) by colliding with generated poitive ions. Then positive ions that have not collided flow away with charged particles to the leeward. Negative ions are generated in the discharge space at the leeward of S.D. (second discharge space). At the same time, positive ions from the windward collide with negative discharge spikes. Therefore “positive ions from the windward” might encourage γ mode discharge on the negative electrodes at the leeward [7][8]. Furthermore as described before, the fact that the ratio of negative discharge occupies the larger part of total discharge might help η become better.

On the other hand, in case of “windward negative corona”, γ mode discharge will not be expected to happen on the positive electrodes at the leeward. Consequently “windward positive corona” leads to the better η comparing to “windward negative corona”.

2.3 Conclusion

In a two-stage-type ESP, spikes for discharge were arranged not only on high-voltage-applied plates but also earth-plates in an ionizer. Under the condition that positive corona and negative corona was simultaneously generated, collection efficiency was measured. The results are as follows.

(1) In the range of larger distance of X, the configulation that the spikes are located at the windward with positive discharge and the spikes at the leeward with negative discharge can realize the better collection efficiency than that of “windward negative and leeward positive”. The reason could be that γ effect at the negative spikes might be enhanced by collision of positive ions from the windward.

(2) In the range of the smallest distance of X, the configulation of “windward negative and leeward positive” shows the better collection efficiency.

(3) The ratio of positive discharge current in total discharge current is from 20 to 40 %.

3 Literature

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